Chapter 3 Pollution

"Implementing the Strategic Action Programme for the South China Sea and Gulf of Thailand (SCS SAP Project)"

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Abstract

Cambodia's coastal and marine pollution is dominated by land-based sources, with estuaries and nearshore waters showing the fastest and most persistent deterioration. Available evidence points to frequent exceedances of nutrient and microbial indicators near urban outfalls and in tourism and aquaculture corridors: estuarine nitrate is reported at about 2.4–2.6 mg/L and phosphate 0.7–0.8 mg/L, while fecal coliforms often exceed 10^5 CFU/100 ml. Offshore conditions remain comparatively moderate, but nearshore hotspots show elevated organic loads and turbidity (BOD ~20–60 mg/L, COD >80 mg/L, TSS ~80–120 mg/L), alongside repeated exceedances of oil/grease and microbial indicators. These pressures are reinforced by intensifying upstream and coastal drivers, including sharply rising pesticide use (from ~445 t in 2000 to >19,000 t by 2023), expanding marine aquaculture (~17,500 t/year with an estimated 25–30% of feed lost as waste), and escalating solid waste and plastics (coastal generation >590 t/day, collection commonly 50–72%, and plastic leakage >14,000 t/year; microplastics measured at ~120–350 particles/kg in nearshore sediments). Industrial and port areas create localized "toxic" hotspots, with around 60% of inspected facilities reported as non-compliant and evidence of hydrocarbon and metal contamination in port-adjacent waters and sediments. While governance and policies exist, core constraints persist—sparse monitoring, fragmented data, weak enforcement, limited treatment coverage (only ~5% of urban wastewater treated; coastal sewerage <20%), and under-resourced hazardous-waste systems—highlighting priority gaps for strengthening monitoring, compliance, infrastructure investment, and cross-sector/spatial planning, including transboundary risk management in the Gulf of Thailand.

Keywords: *Coastal pollution; wastewater; water quality; nutrients; marine litter; plastics/microplastics; hazardous waste; oil and hydrocarbons; enforcement and compliance.*

3. Pollution

3.1. Key Findings, Key Pollution Concerns, and Significance in National and Regional Contexts

- **Land-based sources dominate pollution.** Over 80–90% of pollutants in Cambodia's coastal waters come from land-based activities (untreated wastewater, agriculture, aquaculture, solid waste, industrial zones), causing severe degradation in estuaries and nearshore areas.
- **Nutrient and microbial pollution frequently exceed standards.** Estuaries show nitrate 2.4–2.6 mg/L and phosphate 0.7–0.8 mg/L (above ASEAN limits), while fecal coliforms often exceed 10^5 CFU/100 ml.
- **Nearshore water quality is deteriorating fastest.** Offshore waters remain moderate, but nearshore hotspots show BOD 20–60 mg/L, COD >80 mg/L, TSS 80–120 mg/L and repeated exceedances of oil, grease, and microbial indicators.
- **Agriculture and aquaculture are major nutrient sources.** Fertilizer use is 4–5 times higher than in the early 2000s; pesticides rose from 445 t (2000) to >19,000 t (2023). Marine aquaculture (~17,500 t/year) loses 25–30% of feed as waste.
- **Solid waste and plastics are escalating threats.** Coastal areas generate >590 t/day of MSW, with only 50–72% collected. National plastic waste exceeds 730,000 t/year, coastal leakage >14,000 t/year, and sediments contain 120–350 microplastic particles/kg.
- **Industrial and port activities create toxic hotspots.** About 60% of inspected facilities near ports/SEZs are non-compliant, with high oil & grease, TPH, Pb and Zn; sediment metal levels (e.g. Zn 35–90 mg/kg, Pb 10–25 mg/kg) are rising.
- **Hazardous and medical waste remain weakly controlled.** Industrial waste (~120,000 t/year) and COVID-era medical waste (up to 20 t/day) strain limited hazardous-waste capacity (~150,000 t/year), and smaller generators are poorly monitored.
- **Pollution hotspots overlap sensitive ecosystems.** High-risk zones (Prek Toeuk Sap, Kampot Bay, Kep–Ha Tien, Koh Kong estuary, Phnom Penh confluence) coincide with mangroves, seagrass, Ramsar sites and coral reefs; coral cover near Koh Rong fell from 48% (2010) to ~32% (2023).
- **Ecosystem decline undermines fisheries, aquaculture and tourism.** Fishers report reduced catches, aquaculture faces more disease, and tourist beaches experience closures and visible pollution, with public health risks peaking in the monsoon.
- **Governance exists but enforcement and treatment are weak.** Laws and policies are in place, but inspections are limited, fines rarely applied, and only ~5% of urban wastewater is treated; coastal sewerage coverage is <20%.
- **Cumulative risks are approaching critical thresholds.** Chronic exceedances of TN, TP, FC, TSS and TPH, combined with plastics and industrial pollutants, heighten risks of hypoxia, local ecosystem collapse and long-term economic losses.

3.2 Current Status

3.2.1 Pollution sources and magnitude

3.2.1.1 Agricultural and aquaculture runoff

a) Agricultural runoff

National fertilizer use has risen steeply. Figure 3-*1* show fertilizer consumption per hectare of arable land increasing from **~5–10 kg/ha** in 2003–2008 to roughly **40–50 kg/ha** in 2018–2021, before dipping to **~33 kg/ha** in 2022**,** and moved up to **51kg/ha** in 2023. Over two decades this represents about a four- to five-fold increase.

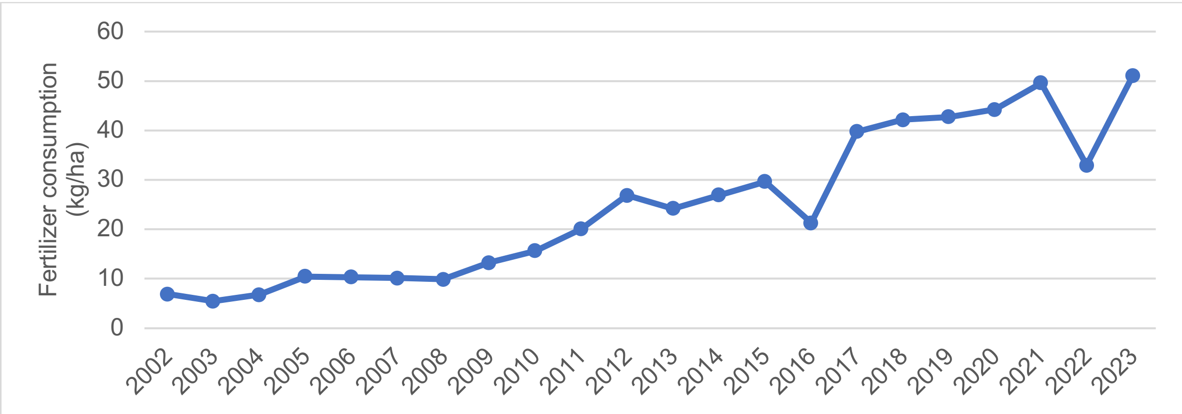

Figure 3-1 Cambodia's national fertilizer consumption (kg/ha of arable land) 2002-2023
Source: *FAOSTAT/World Bank WDI data.*

Recent national compilations indicate fertilizer intensity around **110 kg N + P_2O_5/ha/year**, broadly comparable with other regional deltas (UNEP, 2022). Monitoring in selected estuaries shows rising nutrient concentrations, with **NO_3^- increasing from about 1.8 mg/L (2015) to 2.6 mg/L (2023)** and **PO_4^{3-} from 0.45 to 0.73 mg/L**, above ASEAN guideline values (NO_3^- ≤1.0 mg/L; PO_4^{3-} ≤0.3 mg/L) in some locations (MoE, 2023).

FAOSTAT pesticide statistics (Figure 3-2) show an even stronger rise, from **445 tonnes** in 2000 to **5,330 tonnes** in 2017 and increased to over **19,000 tonnes** in 2023. Pesticide use per unit cropland increased from **~0.12 kg/ha** in 2000 to **0.6–1.1 kg/ha** in 2012–2016 and **2.7–4.2 kg/ha** in 2019–2023 (FAOSTAT RP).

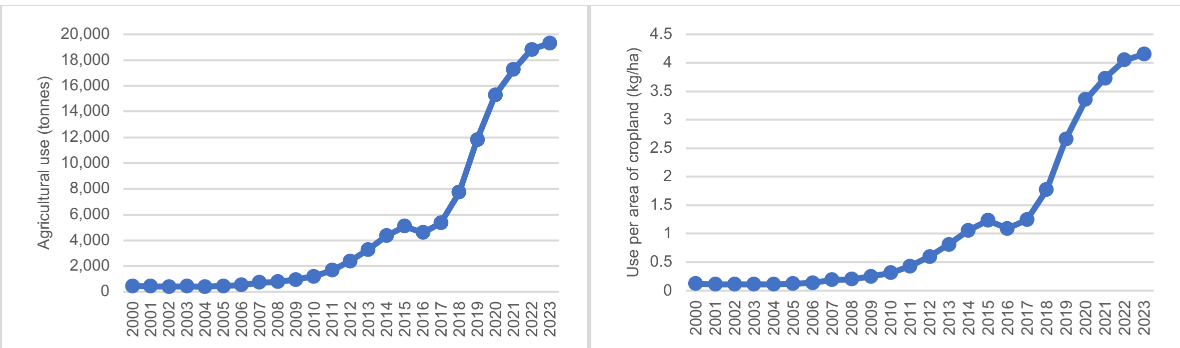

Figure 3-2 Cambodia's national pesticide use (agricultural use & use per area of cropland)
Source: *FAOSTAT, 2023.*

b) Aquaculture runoff

Cambodia's aquaculture sector continues to grow, with **1,934 ha** of aquaculture holdings reported nationally in 2022 (NIS, 2022). Earlier data show the four coastal provinces held **≈1,803 ha** of ponds, pens and cages in 2014 (Kunthy et al., 2021). National aquaculture production reached **≈330,600 tonnes in 2022**, with marine/coastal systems contributing **~5.3%**, or about **17,500 tonnes/year** (WorldFish, 2022; FAO WAPI, 2021). Marine cage farms typically have **FCR 1.6–2.0**, with **25–30%** of feed lost as waste (UNEP, 2022), elevating BOD and TSS in dense farming areas such as Trapeang Ropov and Chroy Svay. Low-value fish made up **60–100% of feed** in 2014, with pellets <1%, increasing organic loads and pressure on wild stocks (Kunthy et al., 2021). Wastewater studies also detect **antibiotic-resistance genes**, indicating antimicrobial use and emerging AMR risks (Pheakdey, C. et al., 2022).

3.2.1.2 Pollution from Major Rivers

Riverine pollution is a major driver of coastal water-quality decline because the Mekong–Tonle Sap–Bassac (MTB) system delivers large loads of nutrients, sediments, organics and microbes to Cambodia's coast and the Vietnamese delta. While the Mekong mainstream is relatively clean due to its high discharge (~14,500 m³/s) with low BOD (1–6 mg/L) and moderate TSS (~85 mg/L) (MRC 2020–2021), microbial contamination remains chronic—**100%** of fecal-coliform samples at Phnom Penh Port exceeded the **1,000 CFU/100 mL** standard in 2021.

Phnom Penh's **Trabek and Tumpun canals** are the largest pollution sources, with **BOD 100–250 mg/L**, **TSS 300–600 mg/L**, **TN up to 8.1 mg/L**, and **TP up to 6.7 mg/L** (JICA; MoE), far above national limits. The Bassac River also carries high loads (**TSS up to 2,030 mg/L; TP ~6 mg/L**) reflecting urban and peri-urban runoff. At **Chroy Changva**, where the Mekong and Tonle Sap systems converge, national datasets show repeated **TN (2018–2019)** and **TP (2012–2019)** exceedances (MoE/WEPA 2023), confirming a persistent nutrient hotspot affecting downstream loads to Viet Nam. The Tonle Sap system shows moderate but significant nutrient levels (TN ~0.9–1.15 mg/L; TP ~0.25–0.32 mg/L), contributing to seasonal eutrophication risks. The **Bassac River at Koh Khel**—the final point before the Viet Nam border—provides key data for estimating transboundary nutrient and microbial export.

Table 3-1 Hydrology and pollution indicators of major rivers – (Cambodia segment)

River Name	River Length (km)	Catchment Area	Annual Discharge	BOD (mg/L)	TSS (mg/L)	Total N (mg/L)	Total P (mg/L)	Total Coliform
Mekong River (Cambodia segment)	~500 km	~795,000 km² (entire basin)	~14,500 m³/s (mean discharge at Phnom Penh)	~1–6.2 mg/L	~85 mg/L	N/A (typically low)	N/A	~3,190 MPN/100 mL
Tonle Sap River & Tonle Sap Lake system	~147 km	~87,940 km²	*No fixed annual discharge due to flow reversal*; seasonal reverse-flow ≈ **30 km³/year**	5.0–6.4 mg/L	11–14 mg/L	0.9–1.15 mg/L	0.25–0.32 mg/L	N/A
Bassac River (Tonle Bassac)	~190 km	~3,568 km²	~10,314 m³/s	6–8 mg/L	300–2,030 mg/L	~40 mg/L	~6 mg/L	~1,000 MPN/100 mL

Source: *MoE/WEPA, 2023; MRC, 2020-2022, JICA, 2010-2013.*

3.2.1.3 Marine and Coastal Water Quality

Offshore waters generally remain in moderate condition, with **DO ~5 mg/L**, **TN 0.2–1.0 mg/L**, and **TP 0.02–0.09 mg/L**, indicating slightly nutrient-enriched but non-hypoxic conditions (MoE/PEMSEA, 2018). In contrast, nearshore estuaries show strong deterioration: **NO_3^- has risen to 2.0–2.6 mg/L** and **PO_4^{3-} to 0.7–0.8 mg/L**, exceeding ASEAN thresholds and reflecting growing inputs from agriculture, aquaculture and untreated wastewater (MoE 2023). TSS remains low offshore (1–15 mg/L) but can exceed **250–320 mg/L** in monsoon-affected estuaries such as Kampot Bay.

Microbial contamination is widespread. Monitoring reports **4,300 MPN/100 mL** in Kep (ADB 2022) and **>10^5 CFU/100 mL** near Prek Toeuk Sap and Ream in Sihanoukville (MoE 2023), driven by sewage and tourism discharges. Hydrocarbon pollution near Sihanoukville Port is persistent, with **TPH ~0.7 mg/L** and **oil & grease ~12 mg/L**, both above national limits.Harmful algal blooms are occasional; two events were reported in Kep in 2016, though no major recent events are documented. While Cambodia has no confirmed persistent hypoxic zones, several semi-enclosed inlets (e.g., Kampot estuary, Trapeang Ropov) show seasonal low DO and recurring eutrophication signals (MoE 2023).

3.2.1.4 Domestic and industrial wastewater

In 2019–2023, combined design capacity of major urban WWTPs (Phnom Penh, Preah Sihanouk, Siem Reap, Battambang) was about **35,000–40,000 m^3/day** (≈11–13 million m^3/year), while estimated urban wastewater generation is several times higher (JICA, 2015; WEPA, 2023). Nationally, centralized plants were estimated to treat only **around 5% of urban wastewater** in 2019, with the remainder managed by septic tanks, on-site systems or discharged untreated (WEPA, 2023; Metawater, 2024).

In the coastal provinces, sewerage coverage is especially low. Recent project information indicates operating WWTPs in **Preah Sihanouk (≈32,400 m^3/day)** and smaller plants in **Kampot and Kep**, but less than **20%** of sewage in key coastal towns is captured and treated (ADB, 2022; MoE, 2023). Household surveys suggest that **fewer than 10%** of households in coastal cities are connected to any urbanization system, with most relying on septic tanks that often overflow to drains and canals during the rainy season. MoE monitoring in 2023 recorded **BOD 20–50 mg/L**, **NH_3-N 1–5 mg/L**, **TSS 80–120 mg/L** and **faecal coliforms 10^4–10^5 CFU/100 mL** in urban canals of Sihanoukville and Kampot—above national effluent and ambient standards under the Sub-Decree on Water Pollution Control (1999).

3.2.1.5 Industrial and port-related wastewater

Industrial zones and port areas are important urbanized sources of wastewater and chemical pollution. At **Sihanoukville Port SEZ**, a central WWTP with design capacity **1,500 m^3/day** serves factories in the zone (JICA, 2024/25). Municipal WWTPs now under construction or commissioning in Preah Sihanouk (total planned **12,000 m^3/day**) will also receive mixed domestic-industrial flows (UNIDO, "Bridge for Cities").

Monitoring of drainage channels in Phnom Penh (Trabek and Tumpun) shows consistently elevated pollutant levels during 2010–2013, with **BOD 100–250 mg/L**, **COD 200–380 mg/L**, **TSS 300–600 mg/L**, **T-N up to 8.1 mg/L**, **T-P up to 6.7 mg/L**, and nutrients and Cr^{6+} frequently exceeding standards (JICA, 2016; DPWT/JICA, 2019). Inspections in the Sihanoukville-port area in 2023 reported non-compliance with effluent standards in around **60%** of inspected facilities. Sample results near the port showed **oil and grease ≈12 mg/L**, **TPH ≈0.7 mg/L**, **Pb ≈0.25 mg/L** and **Zn ≈1.1 mg/L**, all at or above national limits. Coastal sediments near Prek Toeuk Sap and Stung Hav Bay contain elevated metals, with Zn **35–90**

mg/kg, Pb **10–25 mg/kg** and Cu **12–28 mg/kg** (MoE, 2023). The POSEZ industrial estate in Banteay Meanchey has a WWTP designed for **19,000 m³/day**, illustrating the scale of industrial flows nationally (JICA, 2016; Cambodia Chamber of Investment).

3.2.1.6 Solid waste and plastic leakage

Municipal solid waste (MSW) in Cambodia is rising with urbanization and tourism. National MSW reached **≈4.8 million t/year in 2020**, with **0.78 kg/cap/day** in urban areas (Pheakdey et al., 2022). Phnom Penh generates the highest volumes, with per-capita rates declining from **1.32 kg/day (2016)** to **0.98 kg/day (2022)** (UNEP/PPCA, 2018; PPSWMA, 2023). Waste-composition studies show **50–60% organic** and **~20% plastics**; national 3R assessments report **63–80% organic** and **3–16% plastics/rubber/leather** across cities (UNCRD, 2017; MoE, 2023).

Coastal provinces contribute substantial waste: **450–500 tonnes/day** in Preah Sihanouk, **170–200 tonnes/day** in Kampot, **45–55 tonnes/day** in Kep, **≈20 tonnes/day** in Koh Kong town, and **≈2 tonnes/day** on Koh Sdech (Khmer Times, 2021–2023; CamboJA, 2022; UN-Habitat, 2025). Collection efficiency is often **<70%**, with uncollected waste commonly open-dumped or burned near waterways. Cambodia had **~164 dumpsites** in 2020—mostly open dumps lacking liners or leachate control (Pheakdey et al., 2022; ODC, 2023).

Plastic waste is significant: **~730,000 t/year** nationally (RGC/UNEP, 2021). Phnom Penh alone generates **≈0.205 kg/cap/day** of plastics, or **≈262,800 t/year**, assuming ~20% plastic in total waste (PPWMS 2018; UNDP, 2022). Coastal beach and sediment surveys (Otres, Ream, Koh Rong Sanloem) consistently find plastic bags, wrappers and bottles dominating debris, with microplastic levels in sediments reaching hundreds of items/kg**.**

3.2.1.7 Hazardous waste

Data on hazardous waste remain incomplete, but available sources show rising medical and industrial streams. Pre-COVID estimates put Phnom Penh's medical waste at **~40 t/month (~480 t/year)** (GIZ, 2020), surging during COVID-19 to **up to 20 t/day (~7,300 t/year)** (UNDP, 2021). Industrial waste is substantial: a 2021 Korean study estimated **~120,000 t/year** of collected industrial waste, a mixed stream with hazardous components including chemical sludges, metal-bearing wastes, oils, solvents, acids/alkalis and contaminated packaging (KSP, 2021; BSfD, 2023).

Treatment capacity has expanded via the **Chip Mong Ecocycle** co-processing facility in Kampot, with **~150,000 t/year** cement-kiln capacity and **~1,100 t** of hazardous-waste storage (UNCRD, 2023; BSfD, 2023). For medical waste, Cambodia operated **~34 incinerators in 2022**, including five new JICA-supported units.

3.2.1.8 Oil pollution

The most recent documented incident is the **February 2025 oiling at Prek Treng Beach (Preah Sihanouk)**, where an estimated **~2,000 litres** leaked and **≈95%** was cleaned within days (Kiripost; Khmer Times; Cambodianess, 2025). Cambodia has **no consolidated national spill time-series**. The two main international ports—**PAS** (Sihanoukville) and **PPAP** (Phnom Penh)—have reception facilities or contractors for oily waste and bilge water, though annual treatment volumes are not publicly reported (IMO MEPSEAS; JICA). Information on oily-waste handling at **smaller ports, fishing harbors and repair yards** remains limited.

3.2.1.9 Atmospheric pollution

Cambodia's national GHG inventory reports **SO_2 emissions of 32.61 kt** and **NO_x (as NO_2) of 43.43 kt** in 2016, and **territorial CO_2 emissions of about 17,620 kt** in 2022 (UNFCCC, 2019; BUR3). Cambodia participates in the **EANET** acid-deposition network with an urban wet-deposition monitoring site in Phnom Penh. Regional assessments suggest typical urban wet deposition of **>10–30 kg S/ha/year** and **~5 kg N/ha/year** at many East and Southeast Asian sites (EANET PRSAD4, 2022; MICS-Asia III, 2020).

3.2.2 Pollution hotspots and sensitive areas

Monitoring across riverine and coastal stations shows recurring pollution hotspots where BOD, nutrients, solids and microbial indicators exceed standards. At the Mekong–Tonle Sap confluence (CPP), **100% of fecal-coliform samples** in 2021 exceeded the 1,000 CFU/100 mL limit despite low BOD (~1 mg/L), indicating severe microbial loading (MRC 2020–2021). Chroy Changva recorded **TN exceedances (2018–2019)** and repeated **TP exceedance (2012–2019)**, while CTK–Takhmao remains a nutrient hotspot linked to urban expansion. Phnom Penh tributaries Trabek and Tumpun show **extreme pollution** (BOD 100–250 mg/L; TSS 300–600 mg/L; high TN/TP).

In the coastal zone, Kep exceeded **TN, TP and oil & grease** in 2018 (MoE/WEPA). Recent MoE/FIA monitoring identifies hotspots at:

- **Prek Toeuk Sap (Sihanoukville):** BOD 25–60; COD >80; FC >10^5 CFU/100 mL
- **Kampot River:** TSS 120; NO_3^- 2.4; PO_4^{3-} 0.8 mg/L; DO <4 mg/L
- **Tatai estuary:** BOD 20–35; coliform >10^4 CFU/100 mL

These exceed Cambodian coastal standards and ASEAN Class B levels. Sensitive habitats show cumulative impacts: **Peam Krasop sediments** contain **Zn 35–90 mg/kg; Pb 10–25 mg/kg**, and coral cover around **Koh Rong/Sanloem** has declined from ~48% (2010) to ~32% (2023), with strongest impacts near discharge zones.

3.3. Discussion and Conclusions

3.3.1 Priority Transboundary Pollution Issues

3.3.1.1 Mekong–Tonle Sap–Bassac System: Nutrient and Microbial Loads

The MTB system is the primary transboundary pollution route from Cambodia to Viet Nam. At Phnom Penh's CPP station, **fecal coliform exceeded standards in 100% of 2021 samples** (MRC, 2021), reflecting chronic untreated wastewater discharge. Long-term TN and TP exceedances at Chroy Changva (2012–2019) (MoE/WEPA, 2023) and highly polluted tributaries—e.g., Trabek and Tumpun canals with **BOD 100–250 mg/L**, **TP up to 6.7 mg/L**, **TSS up to 600 mg/L**—demonstrate sustained nutrient and microbial loading.

Given **Phnom Penh's** position mid-system, pollutants reach the Vietnamese Mekong Delta within days to weeks, contributing to algal blooms, fish kills, and microbial contamination recorded in the Bassac and Hau Rivers. Upstream FC and solids have been linked to disease outbreaks in Viet Nam's Pangasius farms, with implications for export quality. The Cambodia–Viet Nam Joint Commission has repeatedly emphasized improved wastewater control in Phnom Penh due to its direct effects on delta aquaculture, food safety, and estuarine productivity.

3.3.1.2 Gulf of Thailand Circulation: Marine Litter and Microplastics

Cambodia's coastal provinces leak an estimated **14,400 tons of plastic annually** due to low waste-collection rates (50–68%), open dumping, and burning (MoE, 2024; ADB, 2022). Nearshore sediments already contain **120–350 microplastic particles/kg** (FiA & UNDP 2023), indicating widespread fragmentation and dispersion.

UNEP circulation modelling (2022) shows that plastics from Sihanoukville and Kampot drift toward **Gulf of Thailand's** central convergence zone before returning seasonally to Cambodian waters. Without coordinated monitoring and cleanup, the Gulf may become a regional microplastic hotspot by 2030.

3.3.1.3 Aquaculture-Driven Nutrient and Organic Pollution

Marine aquaculture accounts for only **5–6%** of Cambodia's aquaculture output (~17,000 t/yr) but causes concentrated nutrient and organic loading in shared embayments. Inefficient FCRs (**1.6–2.0**) release **600–1,000 kg** of uneaten feed and waste per tonne of fish, with **25–30%** of feed becoming direct nutrient discharge (UNEP, 2022).

Coastal monitoring shows **TN 0.2–1.0 mg/L** and **TP 0.02–0.09 mg/L** (PEMSEA&MoE, 2018), with elevated values near farms in Kampot, Kep, and Koh Kong—consistent with early eutrophication. In shared estuaries such as **Koh Kong–Trat** and **Kep–Ha Tien**, nutrient enrichment alters plankton communities, reduces juvenile fish survival, and disrupts recruitment of migratory species (anchovies, mackerel, shrimp) exploited by Cambodia, Thailand, and Viet Nam.

3.3.1.4 Hazardous and Industrial Waste: Hydrocarbon and Heavy-Metal Risks

Industrial expansion in Sihanoukville has increased hydrocarbon and metal contamination with cross-border implications. In 2023, waters contained **TPH 0.7 mg/L**, **oil and grease 12 mg/L**, and elevated **Pb (0.25 mg/L)** and **Zn (1.1 mg/L)**—all above national limits (MoE,2023). Sediment records in Peam Krasop and Stung Hav show chronic accumulation (**Zn 35–90 mg/kg**, **Pb 10–25 mg/kg**) linked to industrial effluent, ship repair, and port runoff.

Given Sihanoukville's location on major regional shipping routes, oily waste and spills can reach Thai and Vietnamese waters within days. The **2025 Prek Treng spill (~2,000 L)** highlighted weak surveillance and response capacity. Limited port-reception facilities, incomplete MARPOL enforcement, and the absence of a spill inventory heighten risks of illegal at-sea discharges, contributing to regional hydrocarbon contamination.

3.3.2 Interactions: Impacts on Environment and Society

3.3.2.1 Environmental Interactions

Eutrophication, hypoxia, and ecosystem shifts: Rising nutrient inputs from untreated wastewater, fertilizers, and aquaculture waste are driving eutrophication in estuaries such as Kampot Bay, Prek Toeuk Sap, and the Tatai River. Monitoring shows **NO_3^- up to 2.4 mg/L**, **PO_4^{3-} up to 0.8 mg/L**, and **DO <4 mg/L** (MoE 2023; FiA 2024)—all above national and ASEAN thresholds and consistent with early hypoxia. These conditions trigger dense phytoplankton growth, reduced light penetration to seagrass, and higher risk of harmful algal blooms. Resulting ecosystem shifts favour opportunistic, pollution-tolerant species, reflected in coral declines in Kampot and Kep (**48% to 32%**, 2010–2023; FiA & UNDP 2022).

Habitat degradation from sedimentation, plastics, and suspended solids: High **TSS (80–120 mg/L)**, chronic sedimentation, and **>14,000 t/year** of plastic leakage are smothering mangroves, seagrass, and corals. Sediments contain **120–350 microplastic particles/kg**, indicating accelerating fragmentation (FiA & UNDP 2023). Mangrove cores from Peam Krasop show rising heavy metals (**Zn 35–90 mg/kg; Pb 10–25 mg/kg**), while seagrass beds in Kampot exhibit shorter leaves and heavier epiphyte loads linked to nutrient and sediment stress. Coral reefs around Koh Rong show localized mortality and reduced recruitment near discharge zones.

Toxicity and food-web contamination: Industrial effluents containing **Pb, Zn, Cu**, and hydrocarbons affect reproduction and early-life stages of fish, crustaceans, and mollusks. Elevated metals in sediments near Stung Hav and Prek Toeuk Sap increase risks of bioaccumulation in commercial species. Hydrocarbon contamination (**TPH 0.7 mg/L**) is associated with impaired gill function, higher disease susceptibility, and reduced spawning success. Because many affected species migrate across the Gulf of Thailand, toxicity and contamination have cross-border implications for recruitment and regional fish-stock dynamics.

3.3.2.2 Social and Economic Interactions

Public health risks from microbial and chemical contamination: Extremely high fecal-coliform levels (**>10^5 CFU/100 mL**) in coastal bathing waters and fish-landing sites (MoE 2023) pose immediate health risks, with seasonal spikes in gastrointestinal illness reported in Kampot and Sihanoukville during monsoon periods when runoff and sewage overflow intensify. Chemical risks also arise where heavy metals and hydrocarbons contaminate nearshore waters, exposing low-income, fish-dependent households—especially shellfish consumers—to chronic toxicity.

Impacts on fisheries livelihoods and food security: Pollution reduces fishery productivity through hypoxia, habitat degradation, contamination, and higher disease prevalence in both wild and cultured fish. Small-scale fishers in Kampot and Kep report declining catches and longer travel distances to viable grounds. Aquaculture farmers face higher mortality, greater antibiotic use, and reduced profitability—contributing to emerging antimicrobial resistance (AMR) documented in Cambodian marine aquaculture (IJERPH, 2020). These stresses undermine household food security and erode seafood market competitiveness.

Tourism and coastal-economy degradation: Tourism—one of Cambodia's fastest-growing coastal sectors—is highly sensitive to pollution. Sewage-driven beach closures in Sihanoukville, visible algal blooms, plastic accumulation, and the **2025 Prek Treng oiling incident** have triggered booking cancellations in Koh Rong and Kampot Bay. Environmental decline increasingly deters investors, while reduced tourism revenue further weakens municipal budgets for waste and wastewater management, creating a reinforcing cycle of degradation.

Loss of ecosystem services: Pollution-driven degradation of mangroves, seagrass and coral reefs reduces key ecosystem services: nursery habitat productivity, blue-carbon storage, storm-buffering capacity, and sediment trapping function. These losses increase erosion and coastal vulnerability while undermining long-term climate-adaptation capacity.

3.3.3 Risk Assessment

3.3.3.1 Nutrient Enrichment & Eutrophication

Nutrient loading from agriculture, aquaculture and untreated wastewater represents a **very high-likelihood** systemic risk. Fertilizer use has increased 4–5× since the early 2000s, pesticide inputs exceed **19,000 t/yr**, and coastal provinces release **>21 million m³** of untreated wastewater annually (WDI; FAOSTAT; MoE, 2023). In Kampot Bay, Kep and

Sihanoukville, **NO_3^- 2.4–2.6 mg/L** and **PO_4^{3-} 0.73–0.8 mg/L** exceed ASEAN thresholds, generating **RQ=2–3** and consistent eutrophication symptoms: hypoxia (DO <4 mg/L), recurrent algal blooms, coral decline (**48% to 32%**, 2010–2023), and high TSS (**120–320 mg/L**). Low-flushing sites—Trapeang Ropov, Peam Krasop, Kampot estuary—are especially sensitive, and Gulf-wide circulation gives this risk **high transboundary significance**, affecting shared fisheries and coastal water quality.

3.3.3.2 Microbial Contamination & Public-Health Risk

Microbial contamination is an acute health and environmental risk, with exceedances recorded across riverine and coastal sites. Phnom Penh Port showed **100% FC exceedance** in 2021 (MRC); Sihanoukville canals regularly exceed **10^5 CFU/100 mL**; and Kep recorded **4,300 MPN/100 mL** in 2022 (RQ=4.3). With sewerage coverage below **14%** in coastal provinces, the likelihood of persistent contamination is **very high**, contributing to disease outbreaks, unsafe shellfish harvests, and tourism risks. WQI screening classifies hotspots such as Prek Toeuk Sap, Tumpun Canal and Kampot River mouth as **"poor–very poor"**, requiring urgent wastewater and sanitation interventions. Because microbial loads move through the Mekong–Bassac system and nearshore currents, this risk holds **moderate–high transboundary relevance**.

3.3.3.3 Solid Waste Leakage & Microplastics

Solid waste leakage is a chronic and expanding pressure. Coastal provinces generate **~590 t/day**, with only **50–72%** collection efficiency—resulting in **>14,000 t/year** of plastic leakage (ADB 2022; MoE 2024). Microplastics reach **120–350 particles/kg** in sediments near beaches and ports (FiA & UNDP 2023). The likelihood of ongoing leakage is **high**, driven by unengineered landfills, rainfall, tourism and riverine transport. Impacts include ingestion/entanglement of marine fauna, seagrass and mangrove damage, visual pollution and accumulation in food webs. Gulf circulation transports plastics across borders, giving this category **very high transboundary significance** and **RQ=2–6** relative to regional baseline densities.

3.3.3.4 Industrial & Port-Related Contaminants

Industrial and port-related pollution shows widespread non-compliance as the industrial effluent monitoring shows routine violations of Cambodia's Sub-Decree on Water Pollution Control, as shown in the Table 3-1 below:

Table 3-2 Compliance assessment of key pollution indicators using RQ

Parameter	Observed	Standard	RQ	Compliance Status
Overall facility compliance	60% of inspected facilities **non-compliant**	—	---	**Non-compliant**
Oil & Grease	12 mg/L	5 mg/L	**2.4**	Exceeds limit
TPH	0.7 mg/L	0.5 mg/L	**1.4**	Exceeds limit
Pb	0.25 mg/L	0.1 mg/L	**2.5**	Exceeds limit
Zn	1.1 mg/L	1.0 mg/L	**1.1**	Slightly exceeds limit

Source: MoE, 2023.

Sediments in Sihanoukville, Peam Krasop and Koh Kong show elevated **Zn (35–90 mg/kg)**, **Pb (10–25 mg/kg)** and **Cu (12–28 mg/kg)**—above pre-2000 baselines. Likelihood is **moderate–high** near ports, SEZs and industrial corridors, with hotspots at PAS, Stung Hav, Prek Toeuk Sap and Tumpun–Trabek. Impacts include chronic toxicity, metal bioaccumulation in fish and constraints on aquaculture. Sediment transport along the coast creates **moderate** transboundary risk, especially toward the Cambodian–Thai shelf.

3.3.3.5. Oil Spills & Hydrocarbon Pollution

Oil pollution is episodic but potentially severe. The **2025 Prek Treng spill (~2,000 L)** highlighted vulnerability of beaches and port-adjacent habitats. Chronic low-level releases from bilge water and ship repair are suspected though not well quantified. Likelihood of major spills is **low–moderate**, but consequences are **high**, including smothering of coral and seagrass, fish mortality and tourism disruption. Strong currents mean even moderate spills can drift regionally, giving this category **high transboundary significance**.

3.3.3.6 Hazardous Waste Mismanagement

Hazardous waste management remains limited, with estimates of **~120,000 t/year** of industrial waste potentially containing hazardous fractions (KSP 2021). COVID-19 surges generated **up to 20 t/day** of medical waste (UNDP 2021). With only one co-processing facility and weak tracking systems, the likelihood of improper disposal is **moderate**, with risks of soil/groundwater contamination and toxic residues entering rivers and estuaries. Transboundary significance is **moderate**, mainly through Mekong–Bassac runoff pathways.

3.3.3.7 Cumulative and Systemic Risk

a) Key cumulative risk and impacts

Cambodia's greatest pollution risk arises from **multiple pollutants interacting simultaneously**—nutrients, microbes, plastics, hydrocarbons and metals—pushing ecosystems toward ecological thresholds. Documented cumulative impacts include:

- Persistent hypoxia in sheltered bays (Kampot Bay, Trapeang Ropov).
- Coral and seagrass decline (**48%** to **32%** coral cover, 2010–2023).
- Long-term reductions in fisheries productivity and juvenile habitats.
- Emerging antimicrobial resistance (AMR) in aquaculture environments.
- Major tourism and public-health incidents driven by fecal contamination and algal blooms.
- Regional ecosystem degradation as pollutants circulate across the Gulf of Thailand.

b) High-Risk Geographic Hotspots

Table 3-3 below present the summary of the high-risk geographic hotspots.

Table 3-3 Summary of the high-risk pollution hotspots in Cambodia (Based on RQ, WQI, and Pollutant Exceedances)

Hotspot	Description	Key Indicators
Prek Toeuk Sap – Sihanoukville	Multi-pollutant hotspot with organics, hydrocarbons, microbes	BOD 25–60 mg/L; COD >80 mg/L; TPH RQ=1.4; FC >10^5 CFU/100 mL
Kampot River Estuary & Kampot Bay	High nutrients and sediment loads from agriculture/aquaculture	NO_3^- ≈2.4 mg/L; PO_4^{3-} ≈0.8 mg/L; TSS ≈120 mg/L; DO <4 mg/L
Kep Coast – Ha Tien	Eutrophication-prone transboundary zone	HABs (2016); nutrient exceedances; degraded WQI
Tatai – Koh Kong Estuary	Exposed to mining runoff, domestic wastewater, monsoon sediment	Elevated TSS, metals (local studies)

Phnom Penh Confluence Zone	Severe nutrient/microbial pollution feeding Mekong–Bassac	FC 100% exceedance; TN/TP above standards

Source: MoE (2023), MRC (2021–2022), JICA (2016), WEPA (2023), PEMSEA (2018)

c) Populations Most at Risk

Groups facing disproportionate exposure include:

- Households located along estuaries and canals vulnerable to contaminated water and flooding.
- Communities dependent on seafood, gleaning and nearshore fisheries affected by pathogens, microplastics and metals.
- Tourism-reliant populations in Kep, Koh Rong, Otres and Prek Treng.
- Small-scale aquaculture farmers exposed to disease outbreaks and AMR.
- Children, elderly and immunocompromised people highly sensitive to microbial and chemical hazards.

3.3.4. Interactions: Current Management and Institutions

3.3.4.1 Law and Policy

Cambodia's pollution management framework is now anchored in the **Code on Environment and Natural Resource (2023)**, which consolidates earlier provisions and mandates environmental impact assessment, permitting and pollution control. This is operationalized through key sub-decrees on **Water Pollution Control (No. 27/1999)** and **Solid Waste Management (No. 113/2015)**, which define discharge standards, licensing requirements and basic obligations for waste generators. More recent policies—the **National Policy on Waste Management (2018)**, the **National Action Plan for Marine Plastic Waste Management 2023–2030**, and the **Integrated Coastal Management (ICM) Strategy 2022–2030**—extend this framework to municipal waste, marine litter and integrated coastal planning, with coordination mandated to the **National Committee for Coastal Management and Development (NCCMD)** (NCCMD 2022).

3.3.4.2 Institutions

Pollution monitoring and enforcement are led by the **Ministry of Environment (MoE)** through its Department of Pollution Control and the **Coastal Water Quality Monitoring Network**, with technical support from the **Fisheries Administration (FiA)**, provincial departments and local universities. MoE's **Department of Pollution Control** and its **Coastal Water Quality Monitoring Network** lead national monitoring and compliance inspections. Routine coastal monitoring has been in place since about **2016** at roughly **12 stations** across the four coastal provinces, complemented by river monitoring at stations such as CPP, CTK and Chroy Changva. Core parameters include pH, DO, BOD, COD, NH_3-N, NO_3^-, PO_4^{3-}, oil and grease, and coliform bacteria (MoE 2023).

FiA plays a critical role in addressing aquaculture effluent and coastal habitat degradation, but regulatory reach remains constrained. Cage aquaculture continues to expand in Kampot, Kep, and Koh Kong without routine nutrient discharge monitoring, contributing to eutrophication risks in transboundary estuaries such as **Ha Tien–Kep** and **Koh Kong–Trat**. MPWT oversees ports and navigational safety, including port-reception facilities (PRFs) at PAS and PPAP.

3.3.4.3 Regional and Global Cooperation

Regionally and globally, Cambodia has begun to align its domestic efforts with broader initiatives. It is a participant in the **COBSEA Regional Action Plan on Marine Litter (2021)** and the **ASEAN Framework of Action on Marine Debris**, both of which support implementation of **UNEA resolution 5/14** on a global plastics treaty (COBSEA 2021). These mechanisms provide guidance on monitoring marine litter, developing extended-producer-responsibility (EPR) schemes and strengthening port-reception systems.

On the ground, pilot projects such as the **Sihanoukville Marine Litter Pilot (2022–2024)**—implemented by MoE with UNEP support—have tested community-based segregation, port-side waste reception and beach-cleanup models. They demonstrate that multi-stakeholder approaches (local government, tourism operators, communities) can measurably reduce beach litter and improve awareness.

3.3.5 Gaps and Priority Challenges

Monitoring, data and risk tools: Monitoring coverage remains too sparse and uneven to support reliable RQ/WQI assessments at basin or Gulf scale, and several priority pollutants are monitored irregularly—limiting trend analysis and hotspot detection (MoE, 2023; WEPA, 2023). Data remain fragmented across agencies, with no unified national database or routine, public "environmental report card" (MoE, 2023).

Enforcement and compliance: Industrial non-compliance remains high (≈60% of facilities), with repeated exceedances for BOD, TPH, Pb and Zn (MoE, 2023; UNDP, 2021). Permits and expansions continue even where WWTP performance is weak or absent, while informal dumping/open burning persist due to limited inspection coverage and penalties (MoE, 2023; Business Scouts for Development, 2020).

Infrastructure and financing: Centralized treatment covers only ~5% of urban wastewater, so most effluent is discharged untreated (JICA, 2016; GIZ, 2020). Landfills often function as open dumps, increasing leachate and plastic leakage risks, while hazardous-waste capacity remains limited and under-financed (UNCRD, 2023; MoE, 2023).

Sector integration and land/sea planning: Sector plans rarely include pollution-load or nutrient targets, and spatial planning does not consistently apply carrying-capacity or RQ thresholds when siting/expanding aquaculture, ports, or waste facilities—raising cumulative impacts in sensitive coastal zones (MoE, 2023; WEPA, 2023).

Social and equity dimensions: Canal-side communities, fishers/gleaners, and tourism workers face disproportionate exposure and livelihood impacts; public access to monitoring results and community reporting/grievance channels remains weak (MoE, 2023).

Transboundary and emerging issues: Joint monitoring with Thailand and Viet Nam for marine litter, contamination and hypoxia remains limited (WEPA, 2023). Emerging pollutants (antibiotics/AMR markers, microplastics) are not yet fully embedded in standards or routine monitoring, leaving risk blind spots (MoE, 2023; ODC, 2023).

3.3.6 Recommended Priority Actions

a) Strengthen monitoring, data systems & risk tools

Cambodia should establish a unified national pollution database that integrates MoE, FiA, MRC and JICA-linked datasets, and institutionalize routine RQ/WQI scoring to track priority hotspots. Selected stations should add pesticides, microplastics and AMR markers, and

Cambodia should launch joint monitoring with Thailand and Viet Nam for the Gulf of Thailand and shared estuaries.

b) Reduce nutrient & microbial loads

Priority investments should accelerate sanitation and WWTP coverage in Phnom Penh and coastal towns, targeting the worst canals and outfalls first. Catchment-level nutrient management (buffer strips, fertilizer budgeting and extension support) should be implemented in key agricultural areas, while aquaculture growth should be guided by discharge standards and carrying-capacity assessments for shared embayment.

c) Address solid-waste leakage & marine plastics

Coastal waste services should expand collection coverage and upgrade open dumps toward controlled landfill operations to reduce leakage and leachate. Policy instruments should complement service improvements, including EPR for plastics, deposit-return systems and targeted measures in tourism areas. Successful marine-litter pilots, including those from Sihanoukville, should be scaled nationally, alongside a Gulf of Thailand partnership harmonize monitoring and prevention actions.

d) Control industrial, port-related & hazardous pollution

Compliance should be strengthened through risk-based inspections prioritizing locations where RQ>1, and permit renewals should be tied to verified WWTP performance. PAS and PPAP should report annual oily-waste and hazardous-waste reception volumes to improve transparency. Hazardous-waste handling should be reinforced through available treatment capacity.

e) Protect hotspots & vulnerable communities

Priority hotspots should be designated as pollution-control zones with stricter limits and targeted ecosystem restoration (mangroves, seagrass and wetlands). High-exposure communities should receive practical measures such as safer water options, shellfish/seafood advisories where relevant, and livelihood support. Cambodia should also explore a regional Gulf of Thailand "blue corridor" linking key MPAs to strengthen shared protection efforts.

f) Governance & financing

Mandates should be clarified and operationalized under the 2023 Code on Environmental and Natural Projection, supported by stronger coordination and enforcement. A dedicated coastal/marine pollution fund—combining national budgets, environmental fees and blue-economy/climate finance—would sustain monitoring, infrastructure and restoration. Regional cooperation objectives (COBSEA/ASEAN/MRC) should be embedded in national plans and NDC updates.

3.4 Methodology and Analysis

3.4.1 Overall Approach

The assessment of pollution in Cambodia's coastal and riverine systems followed a structured methodology consistent with the Transboundary Diagnostic Analysis (TDA) framework. The analysis combined **(i) secondary data review**, **(ii) indicator-based assessment**, **(iii) risk screening**, and **(iv) spatial interpretation** of pollutant pathways from land to coast and across borders.

3.4.2 Data Compilation and Validation

Data were compiled from the MoE, MRC, FiA, JICA-supported surveys, WEPA country data, ADB project reports, and peer-reviewed studies. Key data types included: **water-quality parameters** (BOD, COD, DO, nutrients, metals, coliforms); **hydrological datasets** (river discharge, seasonal flows, catchment areas); **waste and effluent statistics** (domestic, industrial, hazardous, medical); marine litter and microplastic surveys; and coastal ecosystem condition data (coral cover, seagrass density, mangrove status). Data were cross-checked across sources to address inconsistencies (e.g., differences in sampling frequency, analytical methods, or units).

3.4.3 Indicator Selection and Scoring

Indicators were selected based on relevance to pollution pathways, availability of time-series data, and alignment with: ASEAN Marine Water Quality Guidelines; Cambodian Water Pollution Control Standards (1999); MRC Water Quality Target Values; and UNEP/COBSEA Regional Marine Litter Indicators. Each indicator was assessed using:

- **Absolute values** relative to national/regional standards
- **Temporal trends** (where multi-year data existed)
- **Spatial exceedances** at hotspot locations
- **Risk Quotients (RQ = observed / standard)**
- **Water Quality Index (WQI) categories**

3.4.4 Risk Quotient (RQ) Analysis

The RQ method was used to screen pollutant exceedances:

RQ = Measured value ÷ Guideline/Standard value

Where:

- **RQ < 1** = compliant / low risk
- **RQ 1–2** = moderate risk / localized exceedances
- **RQ > 2** = high risk
- **RQ > 3–5** = severe risk / likely ecological impact

RQ analysis was applied to nutrients (NO_3^-, NH_3-N, PO_4^{3-}), microbial indicators (MPN/CFU), hydrocarbons (TPH), heavy metals (Pb, Zn, Cu), and solids (TSS).

3.4.5 Water Quality Index (WQI) Screening

WQI categories were calculated using DO, BOD, coliforms, TSS and nutrients where data allowed. Interpretation followed:

- **80–100 = Good**
- **50–79 = Moderate**
- **25–49 = Poor**
- **<25 = Very Poor / unsuitable for direct use**

WQI supported identification of hotspots such as Prek Toeuk Sap, Kampot estuary, and Phnom Penh confluence.

3.4.6 Spatial and Transboundary Analysis

GIS analysis and documented hydrodynamic pathways were used to map: pollution hotspots; estuarine mixing zones; river-to-sea discharge routes; and Gulf of Thailand circulation patterns (e.g., plastic drift, nutrient transport). Transboundary analysis incorporated regional oceanographic models, especially for microplastics and nutrient dispersal toward Viet Nam and Thailand.

3.4.7 Limitations

Key gaps and limitations included: inconsistent monitoring frequencies between agencies; Gaps in microplastics, pesticides, antibiotics, and emerging contaminants; limited long-term time series for estuarine and coastal stations; absence of publicly available WWTP discharge data from SEZs and ports; differences in laboratory methods across datasets (MoE vs. MRC vs. JICA). These constraints were addressed through triangulation, median-value extraction, and RQ/WQI screening to support a defensible TDA-level diagnostic.

Glossary

Term	Definition
AMR (Antimicrobial resistance)	When microorganisms (e.g., bacteria, viruses, fungi, parasites) change over time and no longer respond to antimicrobial medicines, making infections harder to treat.
BOD (Biochemical Oxygen Demand)	The amount of oxygen consumed by microorganisms as they decompose organic matter under aerobic conditions (used as an indicator of organic pollution).
Carrying capacity (aquaculture/ embayment)	The upper level of aquaculture production or resource use that can be sustained over the long term without unacceptable ecological or social impacts ("unacceptable change").
Centralized wastewater treatment plant	The wastewater treatment facility in town, capital, provinces, cities, districts, or khans
COD (Chemical Oxygen Demand)	A measure of chemically oxidizable material in water, approximating the amount of organic/reducing material present.
Deposit-refund / Deposit-return system (DRS)	A surcharge (deposit) added to the price of potentially polluting products that is refunded when the product/packaging is returned, helping prevent pollution.
E. coli (faecal indicator organism)	Considered the most suitable indicator of faecal contamination in drinking-water; should not be detectable in 100 ml in water intended for drinking.
EPR (Extended Producer Responsibility)	A policy approach that makes producers responsible for their products across the lifecycle, including the post-consumer stage (shifting responsibility upstream).
Eutrophication	Enrichment of water by nutrients (especially nitrogen and/or phosphorus) that accelerates algal/plant growth and disturbs ecosystem balance and water quality.
Hazardous waste	Solids, liquids, gases, radioactive substances, explosives, inflammable substances, infectious substances, or substances causing inflammation, rust, oxidation, pollution, cancer or other pollutants causing danger to humans, animals or destruction to plants, public property and the environment. Sources of hazardous waste may be those from housing, markets, supermarkets, recreational sites, public buildings, educational institutions, business activities, services, handicrafts, factories, agricultural activities and mining activities.
Landfill	Any place/site determined by authority or prepared, in compliance with environmental safety measures, for disposal of garbage and solid waste of downtowns.

Liquid-waste	The water which contain environmental pollutant substances which released from direct activities or production of businesses, commercials, or services
Marine litter	Any persistent, manufactured or processed solid material discarded into the sea, rivers or on beaches; brought indirectly by rivers, sewage, stormwater or winds; or lost at sea.
Microplastics	Small plastic pieces less than 5 mm in length.
Oil and grease (HEM)	"n-hexane extractable material" measured by extraction/gravimetry; includes relatively non-volatile hydrocarbons, fats, waxes, soaps and related materials (used as "oil and grease").
Pollution / contaminant "hotspot"	A location where pollutant levels or risk indicators show persistent exceedances or elevated risk requiring prioritized management response.
Recycling	Processing waste materials into products, materials or substances for original or other purposes (diverting from disposal).
Reuse	Using products/materials again for the same purpose (or a similar purpose) without major reprocessing.
RQ (Risk Quotient)	A screening ratio comparing exposure to effects/toxicity (RQ = exposure ÷ toxicity) used to flag higher- or lower-risk situations.
Septic tank	On-site tanks which receive wastewater from toilets and restrooms and stock to breakdown organic waste within the wastewater before discharging into public drainage system.
Sludge	The waste from septic tanks or wastewater treatment system.
Solid waste	Solid waste remained or generated from business activities or services which do not consist of toxic substances or hazardous.
TSS (Total suspended solids)	The concentration of inorganic and organic material retained on a filter (reported as mg/L of dry material per litre of water).
TPH (Total petroleum hydrocarbons)	A broad group/mixture of petroleum-derived hydrocarbons; commonly treated as a measurable quantity of petroleum-based hydrocarbons in an environmental medium.
Wastewater	The water which has been changed its basic elements after using such as household waste, restroom, washing, and wastewater from toilet including urine and stools which released from home, residential buildings, satellite city, business buildings, commercial buildings, services and resorts or recreation center.
WQI (Water Quality Index)	An index combining multiple parameters vs. guideline objectives into a single score (0–100) using scope, frequency and amplitude of exceedances.
WWTP (Wastewater treatment plant/system)	The open canal, reservoirs, pumping station of wastewater or storm water, main pipe system, sub pipe system, technical or natural wastewater treatment plant

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Annex 3

Table of Contents

List of Figures

List of Table

List of Acronyms

ADB	Asian Development Bank
AMR	Antimicrobial Resistance
ARG	Antibiotic-Resistance Gene
ASEAN	Association of Southeast Asian Nations
BOD	Biochemical Oxygen Demand
BSfD	Business Scouts for Development (GIZ)
CAS	Cambodia Agricultural Survey
CFU	Colony-Forming Unit
COD	Chemical Oxygen Demand
COBSEA	Coordinating Body on the Seas of East Asia
CPP	Phnom Penh Port (MRC water-quality station)
CTK	Takhmao Monitoring Station (Bassac River)
DO	Dissolved Oxygen
DPWT	Department of Public Works and Transport
EANET	Acid Deposition Monitoring Network in East Asia
EIA	Environmental Impact Assessment
EPR	Extended Producer Responsibility
FAO	Food and Agriculture Organization of the UN
FAOSTAT	FAO Statistical Database
FC	Fecal Coliform
FCR	Feed Conversion Ratio
FiA	Fisheries Administration
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HAB	Harmful Algal Bloom
ICM	Integrated Coastal Management
IJERPH	International Journal of Environmental Research and Public Health
JICA	Japan International Cooperation Agency
kg/ha	Kilogram per hectare
km^2	Square kilometer
kt	Kilotonne
MAFF	Ministry of Agriculture, Forestry and Fisheries
MICS-Asia	Model Inter-Comparison Study for Asia
MoE	Ministry of Environment (Cambodia)
MPN	Most Probable Number
MPWT	Ministry of Public Works and Transport
MRC	Mekong River Commission
MSW	Municipal Solid Waste
MTB	Mekong–Tonle Sap–Bassac river system
NCCMD	National Committee for Coastal Management and Development
NIS	National Institute of Statistics
NO_3^-	Nitrate
NO_x	Nitrogen Oxides
NSOC	National State of the Oceans and Coasts (PEMSEA)
O&G	Oil and Grease
ODC	Open Development Cambodia

PAS	Sihanoukville Autonomous Port
Pb	Lead
PEMSEA	Partnerships in Environmental Management for the Seas of East Asia
$PM_{2.5}$ / PM_{10}	Particulate Matter
PPAP	Phnom Penh Autonomous Port
PPCA	Phnom Penh Capital Administration
PPSWMA	Phnom Penh Solid Waste Management Authority
PPWMS	Phnom Penh Waste Management System
PRSAD4	4th Periodic Report on the State of Acid Deposition (EANET)
RGC	Royal Government of Cambodia
RQ	Risk Quotient
SEAFDEC	Southeast Asian Fisheries Development Center
SEZ	Special Economic Zone
SO_2	Sulfur Dioxide
TDA	Transboundary Diagnostic Analysis
TN	Total Nitrogen
TP	Total Phosphorus
TPH	Total Petroleum Hydrocarbons
TSS	Total Suspended Solids
UNCRD	United Nations Centre for Regional Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WAPI	World Aquaculture Performance Indicators (FAO)
WEPA	Water Environment Partnership in Asia
WQI	Water Quality Index
WWTP	Wastewater Treatment Plant
Zn	Zinc

Annex 3-1 Dataset and analysis framework, and complimentary note

A. Core Water-Quality Indicators

This annex consolidates the core water-quality indicators used to diagnose organic pollution, nutrient enrichment and microbial contamination in Cambodia's rivers, estuaries and coastal waters. It draws primarily on MoE's river and coastal monitoring network, the Mekong River Commission's Water Quality Monitoring Network (WQMN), and JICA drainage and sewerage studies in Phnom Penh. These datasets provide multi-year information on BOD, TSS, total nitrogen (TN), total phosphorus (TP), and fecal coliforms/E. coli, which together underpin the RQ and WQI analyses in the chapter.

The indicators are used to detect hotspots where nutrient and microbial concentrations exceed Cambodian and ASEAN standards, and to trace land-based pollution pathways from Phnom Penh and major tributaries to coastal estuaries such as Kampot, Kep and Prek Toeuk Sap. Time-series trends (2010–2023) help identify whether conditions are improving, stable or deteriorating, and provide an empirical basis for classifying risk levels and prioritising interventions.

Annex Table 3-1 Core water-quality indicators: data sources, metadata, and assessment method

Category	Details
Data Sources	• MoE river & coastal monitoring network (BOD, TSS, TN, TP, FC; c.2015–2023) • MRC WQMN (Mekong, Tonle Sap, Bassac stations; nutrients & coliforms; 2012–2022) • JICA drainage & sewerage studies for Phnom Penh canals (Trabek, Tumpun; 2010–2013) • ADB/MoE special surveys in Kep and selected estuaries.
Metadata	• Parameters: BOD, TSS, TN, TP, fecal coliforms/E. coli. • Units: mg/L (BOD, TSS, TN, TP); CFU/100 mL or MPN/100 mL (microbial). • Coverage: main Mekong–Tonle Sap–Bassac stations plus coastal/estuarine sites in Kampot, Kep, Koh Kong, Preah Sihanouk. • Frequency: typically monthly–quarterly; higher for some JICA canal datasets. • Reference standards: Cambodian ambient water standards and ASEAN Marine Water Quality Guidelines.
Assessment Method	• Compute RQ = observed / standard for each parameter and station to classify risk (RQ<1 compliant; 1–2 moderate; >2 high; >3–5 severe). • Derive simple Water Quality Index (WQI) classes (good–very poor) from DO, BOD, TN/TP, coliforms and TSS where data allow. • Map hotspots where multiple parameters exceed thresholds over several years (e.g. Phnom Penh confluence, Kampot estuary, Prek Toeuk Sap). • Compare trends over time to judge whether nutrient and microbial loads are increasing or stabilising.

The combined BOD, TSS, TN, TP and coliform datasets demonstrate that chronic nutrient and microbial exceedances now affect multiple estuaries, particularly downstream of Phnom Penh and in semi-enclosed coastal bays. RQ and WQI scores highlight "poor–very poor" conditions in canals and estuaries feeding the Mekong–Bassac system and key coastal hotspots, supporting the chapter's conclusion that untreated wastewater, agriculture and aquaculture are the dominant drivers of eutrophication and public-health risk.

Annex Table 3-2 Water quality indicator summary (BOD, TSS, TN, TP, FC)

Indicator	Units	Data Sources	Sampling Frequency	Method / Standard	Key Use in Analysis

BOD	mg/L	MoE; MRC; JICA	Monthly–Quarterly	APHA 5210 B (5-day BOD)	Organic pollution; wastewater load; RQ & WQI sub-index
TSS	mg/L	MoE; JICA; MRC	Monthly–Seasonal	Gravimetric method	Sediment stress, estuary siltation, coastal turbidity
Total N (TN)	mg/L	MoE; MRC; WEPA	Monthly–Quarterly	Spectrophotometric (APHA 4500-N)	Nutrient enrichment; eutrophication; RQ mapping
Total P (TP)	mg/L	MRC; MoE	Monthly–Quarterly	Molybdenum Blue (APHA 4500-P)	Eutrophication; bloom risks; hotspot detection
Fecal Coliform / E. coli	CFU/100 mL	MoE; ADB; MRC	Monthly	MPN (Multiple-tube)	Public health risk; WQI microbial index; tourism risk

B. Industrial and Port Pollutants*:* Hydrocarbons (Oil & Grease, TPH) *and* Heavy Metals (Pb, Zn, Cu)

This annex summarises data on hydrocarbons (oil & grease, total petroleum hydrocarbons – TPH) and heavy metals (Pb, Zn, Cu) in port areas and coastal sediments. The main focus is Sihanoukville Port and surrounding SEZs, as well as industrialised estuaries such as Prek Toeuk Sap and Stung Hav. Monitoring by MoE, complemented by FiA/UNDP habitat studies, documents both water-column exceedances of national effluent standards and long-term metal accumulation in mangrove and estuarine sediments.

These indicators are used to identify toxic “hotspots” where industrial and port activities pose risks to marine life, food safety and transboundary pollution through Gulf of Thailand currents.

Annex Table 3-3 Industrial and port pollutants: data sources, metadata, and assessment method

Category	**Details**
Data Sources	• MoE industrial effluent and port-area monitoring (oil & grease, TPH, Pb, Zn; 2022–2023). • MoE sediment studies in Peam Krasop, Stung Hav, Koh Kong estuaries (metals, hydrocarbons). • FiA/UNDP habitat assessments (mangrove and seagrass sediment cores). • SEZ and port environmental reports (PAS, SEZ WWTP performance).
Metadata	• Parameters: Oil & Grease, TPH, Pb, Zn, Cu. • Units: mg/L (water), mg/kg (sediment). • Spatial focus: Sihanoukville Port, Prek Toeuk Sap, Stung Hav Bay, selected mangrove sites in Koh Kong and Peam Krasop. • Standards: Cambodian effluent limits (e.g. O&G ≤5 mg/L; TPH ≤0.5 mg/L; Pb ≤0.1 mg/L; Zn ≤1.0 mg/L) and international sediment-quality guidelines.
Assessment Method	• Calculate RQ for each parameter relative to national limits to assess facility compliance (e.g. RQ>1 for O&G, TPH, Pb, Zn). • Compare sediment concentrations with pre-2000 baselines and guideline values to infer long-term accumulation and ecological risk. • Identify spatial clusters of non-compliance and sediment hotspots around ports and SEZ discharges. • Qualitatively link hotspots to industrial activities, ship repair zones and port drainage patterns.

The industrial and port-pollution datasets show that around 60% of inspected facilities are non-compliant with effluent standards, with RQ values >1 for oil & grease, TPH, Pb and Zn in port-adjacent waters. Sediment records confirm chronic accumulation of metals in mangrove and estuarine environments, signalling long-term toxicity risks for benthic organisms and seafood consumers, and underlining the need for stronger port-based controls and hazardous-waste management.

Annex Table 3-4 Industrial/port pollutants (hydrocarbons & heavy metals) indicator summary

Indicator	Units	Data Source	National Standard	Methods	Notes
Oil & Grease	mg/L	MoE (2022–2023)	≤5 mg/L	Infrared spectro	Exceedances at PAS, Stung Hav
TPH	mg/L	MoE	≤0.5 mg/L	GC or IR	Chronic low-level contamination around port
Lead (Pb)	mg/L (water) / mg/kg (sediment)	MoE; FiA/UNDP	≤0.1 mg/L	AAS	Sediments show 10–25 mg/kg accumulation
Zinc (Zn)	mg/L / mg/kg	MoE	≤1.0 mg/L	AAS	Elevated in estuaries (35–90 mg/kg)
Copper (Cu)	mg/kg (sediment)	MoE; FiA	—	AAS	Consistent increase in sediments (12–28 mg/kg)

C. Solid Waste and Marine Litter

This annex collates data on municipal solid waste generation, collection efficiency, marine litter and microplastic contamination in coastal areas. It integrates MoE national waste baselines, municipal waste data from coastal provinces, UNDP and ADB beach-litter surveys, and FiA/UNDP sediment microplastic studies.

These datasets are used to estimate plastic leakage from land to sea, document spatial patterns of beach litter, and quantify microplastic abundance in nearshore sediments, providing a basis for assessing Cambodia's contribution to regional marine-litter loads in the Gulf of Thailand.

Annex Table 3-5 Solid Waste, Marine Litter and Microplastics: Data Sources, Metadata, and Assessment Method

Category	Details
Data Sources	• MoE National Waste Baseline and provincial waste diagnostics (2018–2023). UNDP and ADB studies on municipal waste and marine litter in Phnom Penh and coastal cities. • Beach-litter surveys following UNEP/COBSEA protocols (ADB, UNDP). • FiA & UNDP sediment microplastic surveys (Otres, Ream, Koh Rong/Sanloem, Kep).
Metadata	• • Indicators: waste generation (t/day, t/year); collection coverage (%); plastic fraction of MSW; beach-litter density (items/m²); sediment microplastic abundance (particles/kg). • Spatial coverage: four coastal provinces plus Phnom Penh; key beaches and ports. • Timeframe: baseline around 2018–2023; some trend data for Phnom Penh.
Assessment Method	• Combine generation and collection data to estimate uncollected waste and coastal plastic leakage (>14,000 t/year). • Use standardised transects to compare litter densities across sites and identify tourism-dominated hotspots. • Analyse microplastic counts in sediments (120–350 particles/kg) to classify contamination levels and associate with nearby sources (ports, river mouths, tourism areas). • Interpret results in relation to regional circulation models to infer transboundary transport of plastics and microplastics.

The solid-waste and marine-litter datasets show that low collection rates and unengineered dumpsites generate substantial plastic leakage to rivers and coastal waters. Beach and sediment surveys confirm that plastics dominate shoreline debris and that microplastic contamination is already widespread near ports and tourist beaches. These findings support the chapter's conclusion that marine litter and microplastics represent a rapidly escalating, transboundary pollution issue requiring coordinated land-based waste reforms and Gulf-wide cooperation.

D. Hazardous and Medical Waste

This annex synthesises information on industrial hazardous waste and medical waste, including COVID-19-related surges, and compares estimated waste generation with national treatment capacity. It draws on UNDP and Business Scouts for Development (GIZ) sector studies, Korean knowledge-sharing programmes, UNCRD country summaries, and facility data for the Chip Mong Ecocycle co-processing plant and medical-waste incinerators.

The indicators are used to assess whether hazardous and medical wastes are likely to be managed within licensed facilities or are at risk of informal dumping, co-disposal with municipal waste or uncontrolled burning.

Annex Table 3-6 Hazardous and medical waste: data sources, metadata, and assessment method

Category	Details
Data Sources	• UNDP and GIZ/Business Scouts sector briefs on waste management and medical waste (2020–2023). • Korean KSP/KDI policy studies on industrial waste. • UNCRD reports on hazardous-waste co-processing in cement kilns. • MoH and facility reports on medical-waste incineration capacity.
Metadata	• Indicators: estimated industrial hazardous/"collected industrial" waste (t/year); routine and COVID-peak medical waste (t/year); licensed co-processing capacity (~150,000 t/year); number and size of medical-waste incinerators (~34 units). • Spatial coverage: national, with concentration in Phnom Penh and industrial hubs; co-processing facility in Kampot.
Assessment Method	• Compile reported waste generation by sector and compare with licensed treatment capacity to identify gaps and potential uncontrolled disposal. • Map provinces and sectors without reasonable access to licensed hazardous-waste facilities. • Classify overall risk qualitatively (low/medium/high) based on generation-to-capacity ratios, transport distances, and known informal practices (open burning, on-site burial, co-disposal at dumpsites).

Available data suggest that industrial and medical hazardous wastes are increasing faster than licensed treatment capacity. While the Kampot co-processing facility provides substantial nominal capacity, geographic concentration and limited coverage for smaller generators mean that many hazardous streams are likely mismanaged. This reinforces the chapter's conclusion that hazardous-waste mismanagement is a medium but growing risk, especially where residues can leach into waterways or be co-disposed with municipal waste in unlined dumps.

Annex Table 3-7 Hazardous and medical waste indicator summary

Category	Indicator	Units	Sources	Methods	Notes
Industrial hazardous waste	Estimated industrial hazardous/collected industrial waste	t/year	UNDP (2021); Business Scouts for Development (2023); KSP/KDI studies; facility reports	Compile reported annual waste volumes by facility/sector; compare with national hazardous-	Around 120,000 t/year "collected industrial waste" reported; only a portion formally recorded as hazardous; significant uncertainty on

				waste definitions	informal/unregistered generators.
Medical waste (pre-COVID)	Routine medical waste generation	t/year	UNDP (2021); MoH/health-facility reports	Sum reported monthly/annual waste from hospitals and health centres; extrapolate to national level	Pre-COVID estimates ≈40 t/month (~480 t/year) in Phnom Penh; lower volumes in provinces with weak reporting.
Medical waste (COVID surge)	Pandemic-related surge in medical waste	t/year	UNDP (2021); emergency-response documentation	Compare peak daily generation with pre-COVID baselines; estimate annualised surge	COVID period peaks up to ~20 t/day (~7,300 t/year) in Phnom Penh; stress-tested existing incinerators and storage capacity.
Treatment capacity – co-processing	Hazardous-waste co-processing capacity (cement kiln)	t/year	UNCRD (2023); company reports (Chip Mong Ecocycle)	Review licensed capacity; cross-check with reported annual inputs	Nominal capacity ≈150,000 t/year; actual throughput lower; capacity mainly in Kampot, far from northern/remote generators.
Treatment capacity – medical waste	Number and capacity of medical-waste incinerators	units; t/year	GIZ (2020); UNCRD (2023); MoH	Inventory of installed incinerators; estimate throughput based on design capacity and operating days	~34 incinerators nationwide (incl. 5 new JICA units); many small, intermittent operation; limited emission controls and ash management.
Sectoral risk mapping	Mismatch between waste generation and licensed treatment	ratio; qualitative rating	All above	Compare estimated generation vs. licensed capacity; map provinces with no access to licensed facilities	High-risk sectors: small/medium industries, clinics, labs; risks include illegal dumping, on-site burial, co-disposal with municipal waste and open burning.

E. Hydrology and atmospheric (Discharge, Catchment Area, Flow Reversal)

This annex summarises the hydrological and atmospheric datasets used to understand how pollutants are transported from inland hotspots to the coast and across borders. It relies on MRC hydrological records (discharge, flow reversal, catchment areas), MoE/WEPA reports, and regional acid-deposition and air-pollution assessments (EANET/PRSAD4, MICS-Asia).

Hydrological indicators are used to estimate pollutant loads (BOD, TSS, TN, TP) at key stations and to identify major river-to-sea pathways, while atmospheric datasets frame the relative contribution of airborne sulphur and nitrogen deposition to coastal nutrient budgets.

Annex Table 3-8 Hydrology and transport: data sources, metadata, and assessment method

Category	Details
Data Sources	• MRC hydrological datasets for Mekong, Tonle Sap and Bassac (discharge, TSS). • MoE/WEPA water-environment assessments. • Peer-reviewed studies on Tonle Sap flow reversal and catchment characteristics. • EANET PRSAD4 and related regional modelling (MICS-Asia) for SO_2 and NO_x deposition.
Metadata	• Indicators: mean and seasonal discharge (m³/s); reverse-flow volume for Tonle Sap (~30 km³/year); TSS and nutrient concentrations at key stations; wet deposition of nitrogen and sulphur (kg/ha/year). • Spatial coverage: Mekong mainstream, Tonle Sap River, Bassac River (Koh Khel/border), and main coastal rivers (Kampot, Tatai, Prek Toeuk Sap). • Temporal coverage: mainly 2010–2022, with longer historical context where available.
Assessment Method	• Calculate annual pollutant loads (t/year) using L = C × Q × conversion factor, where concentration and discharge data co-exist. • Rank river reaches and tributaries by relative contribution to downstream nutrient and sediment loads. • Use qualitative pathway mapping to trace transport from Phnom Penh canals and MTB system to the Vietnamese delta and Gulf of Thailand. • Interpret atmospheric deposition data in relation to terrestrial nutrient sources to judge its relative significance.

Hydrological analysis confirms that the Mekong–Tonle Sap–Bassac system is the dominant pathway for nutrient and microbial export from Cambodia to the Vietnamese delta, while coastal rivers such as Kampot and Tatai deliver concentrated loads from local agricultural and urban sources directly to sensitive estuaries. Combined with regional circulation and deposition data, these findings underpin the chapter's identification of transboundary pollution linkages in both riverine and marine compartments.

Annex Table 3-9 Hydrology (discharge, catchment area, flow reversal) indicator summary

Category	Indicator	Units	Sources	Methods	Notes
Mekong mainstream	Mean annual discharge at Phnom Penh / Kratie	m³/s	MRC hydrological datasets; MRC annual reports	Analyze long-term gauging-station records; compute mean and seasonal range	Mekong at Kratie ≈14,500 m³/s (order of magnitude); large discharge provides strong dilution but also rapid downstream transport of pollutants.
Bassac River (Tonlé Bassac)	Discharge at Koh Khel / border reach	m³/s	MRC WQMN & hydrology; national river reports	Use rating curves and stage–discharge relationships; interpolate for missing years	Key conduit of Phnom Penh pollutants to Viet Nam; discharge ~10,000 m³/s in wet season; used for pollutant-load estimates where concentration data exist.
Tonlé Sap River & Lake	Catchment area; reverse flow volume	km²; km³/year	Peer-reviewed Tonlé Sap studies; MRC basin reports	Derive catchment from GIS; use published reverse-flow estimates (e.g., 30 km³/year)	Catchment ≈87,940 km²; unique flow reversal sends Mekong water into the lake in wet season and back out in dry season, redistributing nutrient and sediment loads.

National river network	Major river lengths & catchments (Mekong, Tonlé Sap, Bassac, coastal rivers)	km; km²	MRC & MoE river atlases; national topographic maps	GIS delineation of catchments; digitised river networks	Used to normalise pollutant loads (e.g., t/year per km²) and to identify sub-basins contributing to coastal hotspots (Tatai, Kampot, Prek Toeuk Sap).
Pollutant load estimation	Loads for BOD, TSS, TN, TP at key stations	t/year	Combination of hydrological data (MRC) and water-quality datasets (MoE, JICA, MRC)	Apply L = C × Q × 31.536 (for mg/L × m³/s → t/year); seasonal disaggregation where wet/dry data available	Load estimates are used to rank river reaches as low/medium/high contributors to downstream coastal pollution; uncertainties flagged where discharge or concentration data are sparse.
River-to-sea pathway mapping	Connectivity from inland hotspots to coastal/ transboundary zones	qualitative (maps; pathway descriptions)	All above; plus regional circulation studies	Overlay river network, discharge, and monitoring hotspots; trace main pollutant pathways to Gulf of Thailand and Vietnamese delta	Highlights Phnom Penh–Bassac–Viet Nam pathway and coastal rivers (Kampot, Tatai, Prek Toeuk Sap) as primary transport routes for land-based pollution to marine ecosystems.

Annex Table 3-10 Coastal & riverine pollution risk assessment

Risk category	Main pollutants / drivers	Likelihood	Key impacts	Main hotspots	Transboundary significance
Nutrient enrichment & eutrophication	Fertilizer and pesticide runoff, aquaculture effluent, untreated municipal wastewater (NO_3^-, PO_4^{3-}, TSS)	**Very high**	Hypoxia (DO <4 mg/L), algal blooms, coral-cover decline, seagrass stress, reduced fisheries productivity	Kampot Bay, Kep, Sihanoukville, Trapeang Ropov, Peam Krasop, Kampot estuary	**High** – nutrients and organic matter transported within Gulf of Thailand and affect shared fisheries and water quality
Microbial contamination & public-health risk	Fecal coliforms, pathogens from low sewerage coverage and direct discharge	**Very high**	Waterborne disease, unsafe bathing water, fish-landing contamination, shellfish and food-safety risks, tourism losses	Phnom Penh Port/MTB system, Sihanoukville canals, Kep coastal waters, Prek Toeuk Sap, Tumpun Canal, Kampot River mouth	**Moderate–high** – microbial loads exported via Mekong–Bassac and coastal currents
Solid waste leakage & microplastics	Poorly managed municipal solid	**High**	Ingestion/entanglement of fauna, seagrass and mangrove damage, beach and	Coastal cities and landfills in Koh Kong, Sihanoukville	**Very high** – plastics transported around Gulf of

	waste, plastics from tourism and urban areas		seabed litter, long-term microplastic buildup, visual pollution	, Kampot, Kep; beaches and port areas	Thailand, contributing to regional hotspots
Industrial & port-related contaminants	Non-compliant effluents (oil & grease, TPH, Pb, Zn, Cu) from SEZs, industry and ports	**Moderate–high** (spatially concentrated)	Chronic toxicity, bioaccumulation in fish, estuarine habitat degradation, constraints for aquaculture	Sihanoukville Autonomous Port, Stung Hav cluster, Prek Toeuk Sap, Tumpun–Trabek canal system, Peam Krasop/Koh Kong	**Moderate** – contaminated sediments and plumes transported along nearshore shelf (esp. toward Thai border)
Oil spills & hydrocarbon pollution	Episodic spills, bilge water, ship repair and port operations	**Low–moderate** (but high consequence)	Acute smothering of coral and seagrass, fish kills, beach closures, tourism disruption, residual hydrocarbons in sediments	Port-adjacent waters, shipping lanes near Sihanoukville , Prek Treng coastline	**High** – strong currents can move slicks across borders within days
Hazardous waste mismanagement	Poorly tracked industrial, medical and hazardous wastes; limited treatment capacity	**Moderate**	Soil and groundwater contamination, toxic residues entering rivers/estuaries, long-term human-health risks	Industrial corridors, urban disposal sites, facilities lacking secure treatment	**Moderate** – mainly via Mekong–Bassac and coastal runoff pathways